

# Identifying limiting factors for feasible productivity improvement for smallholder farmers in coffee sector in Indonesia

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**Abstract.** *Tran HTM, Nathan S, Ilmma A, Burkiewicz M, Wisana IDGK. 2021. Identifying limiting factors for feasible productivity improvement for smallholder farmers in coffee sector in Indonesia. Asian J Agric 5: 53-60.* Coffee is a global commodity with significant value-addition and export potential for producing countries. The purpose of this study was to identify the important factors associated with increasing yields. Rather than prescribing theoretical solutions, our research purpose was to examine the prevailing agricultural practices that are used in the region and identify the top three factors that have a significant impact on yields. Using advanced data collection methods and controlling for regional characteristics and various farming practices, we found that higher yield was associated with the application of fertilizer, higher tree density, and shade level. The application of fertilizer was associated with an increase in yield of 98 kg/ha for Arabica and 124 kg/ha for Robusta. At the optimal density ranges, a higher yield can be obtained with the increase of trees. Lastly, the level of shade was negatively associated with yield for Arabica, but no significant difference was observed for Robusta. We found a lot of headroom to increase the yield, as the current fertilizer application was low especially for Robusta, a mismatch between optimum tree density for both Arabica and Robusta, and opportunities for better shade management to increase yield potential.

**Keywords:** Coffee, density, fertilizer, shade, yield

## INTRODUCTION

Coffee is a global commodity with significant value-addition and export potential for producing countries, many of which are either poor or developing economies. In terms of the total area planted, Indonesia is the world's second-largest; but Indonesia ranks 4th in terms of coffee production with an average yield of 692 kgs of green bean per hectare. This is far below the yield of other leading coffee-producing countries such as Vietnam, Columbia, and Brazil (Ministry of Agriculture 2017). With a total production of 666,992 tons and 70% of them exported, coffee is a primary contributor to Indonesia's export, raking in more than \$1bn in export earnings (Indonesian Coffee Statistics 2017). Indonesia's total coffee area is about 1.2 million hectares, and smallholder households numbering 1.8 million own and manage 96.26% of them. The two main species grown are Robusta, accounting for 73% (0.86 million ha), and Arabica accounting for 27% (0.31 million ha) (Ministry of Agriculture 2017). In the last few years, the demand for Arabica coffee is growing due to the rise in prices led by the global appetite for specialty coffee.

Smallholders, who produce most of the country's coffee, often do not have access to quality processing facilities and thus resort to low-quality processing at a farm

level. The adoption of good agricultural practices is also quite low, hampering yields. Such challenges, coupled with the fragmented landholding nature of smallholders do not bode well with the sustainable development of rural coffee-growing communities. Comparing the 692 kg ha<sup>-1</sup> yield of Indonesia with neighboring Vietnam's yield of 2,400 kg ha<sup>-1</sup> sets a reasonable benchmark of the yields that are achievable through the right policy and development interventions.

Through this paper, we set out to identify the important factors associated with yield improvements. Rather than resorting to theoretical solutions, our research examines the prevailing agricultural practices in the key coffee-growing regions of Sumatra. By interviewing thousands of farmers and employing advanced statistical methodologies, we identified the top three factors that have a significant impact on yields.

We chose to research yields as Indonesia has significant headroom to increase per hectare yields. Also, the increased income a smallholder can derive from higher yields should help strengthen their livelihoods and build resilient rural communities. In the medium-to-long term, it should also pave the way for the nation's inclusive growth and sustainable development.

## MATERIALS AND METHODS

### Data collection

The study uses data from The Enveritas Coffee Survey (ECS)\* in 2018 that collected information about social, environmental, and economic aspects of coffee farming such as farming practices, productivity, coffee pricing, access to training and finance, relationship with workers, health and safety aspects, biodiversity, soil and water conservation, and chemicals usage. The ECS utilizes cutting-edge machine learning to identify coffee growing regions in seven provinces in Sumatra (Aceh, North Sumatra, West Sumatra, Bengkulu, Jambi, South Sumatra, and Lampung). Based on the population data from the Ministry of Agriculture (MoA) and National Statistics Office (BPS), we first mapped the population of coffee farmers of all districts in seven provinces in Sumatra. From this, we defined a new population unit called “supply units” (SU) which consisted of bordering districts in such a way that each supply unit contained approximately 10,000 coffee farmers (Figure 1.A). The formation of supply unit allowed us to better compare parameter estimates across regions, as it does not depend on the administrative boundaries that can be very different from region to region. In total, we had 68 supply units across seven provinces in Sumatra.

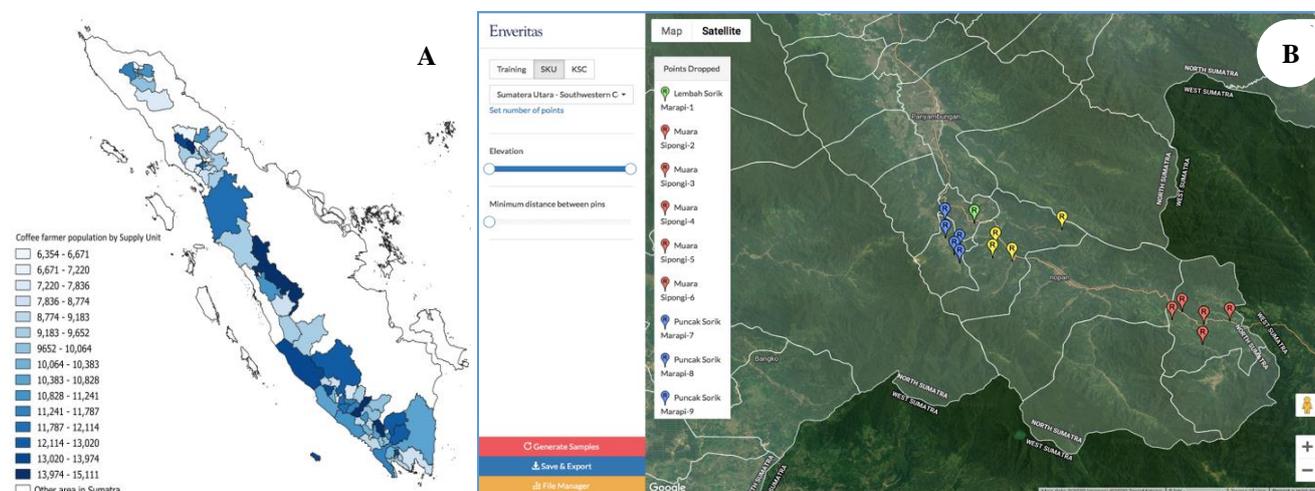
Through advanced data collection methods, ECS obtained representative samples of coffee farmers reaching out to even the remotest villages. For sample randomization, machine learning algorithms were applied to high-resolution satellite imagery to detect coffee-growing households. Our geo-randomization tool provided random drop pins across the supply units (Figure 1.B). Our field team of enumerators went to the drop pins location and looked for 5 coffee farmers within 2 km radius. Each randomized farmer household was interviewed in-person and on-site by the enumerators through a mobile application. Survey results and field observations

underwent rigorous quality control and outlier detection process before acceptance.

We interviewed around 120 coffee farmers in each supply unit and achieved a less than 10% margin of error. Table 1 shows the overview of data collection of ECS survey. In total, ECS collected 8,236 survey data sets representing around 700,000 coffee farmers across seven provinces and 44 districts in Sumatra. The surveys were conducted during the harvest periods of respective regions that can provide more representative information regarding coffee farming activities (October-December 2018 for Northern Sumatra and April-July for Southern Sumatra). Backchecks on a sample size of around 8% were done to ensure data integrity. The average length of a survey was 62 minutes. The average age of farmer’s interviewed was 47 years, of which 30% were female.

**Table 1.** Overview of the farm and household characteristics

Information	Description
Number of provinces	7
Number of districts	44
Total number of supply units	68
Total number of surveys:	8,236
Southern Sumatra (West Sumatra, Bengkulu, Jambi, South Sumatra, and Lampung)	2,914
Northern Sumatra (Aceh and North Sumatra)	5,322
Data collection period:	
Northern Sumatra	Oct-Dec 2018
Southern Sumatra	Apr-Jul 2018
Average number of surveys for each supply unit	121
Average survey length	62 minutes
Demographic information:	
Average coffee farmer’s age	47 years old
Gender	30% of farmers interviewed are female



**Figure 1.** Identifying coffee growing location and sample randomization. A. Number of farmer by supply unit. B. Illustration of Enveritas’ geo-randomization tools. The tools randomly drop a set of pins to which the enumerators will go to do the surveys.

## Data analysis

Our research focused on finding several possible factors that correlated with yield including fertilizer application, tree density, levels of shade tree, chemical application, pruning, and replanting. Multiple linear regression was used by differentiating between Arabica and Robusta species. Farmer's characteristics such as farm size, exposure to farming-related training, experience of growing coffee, and hiring labor as well as provincial dummies were used as additional controls. In addition to yield, we also used yield per tree, total revenue, and revenue ha<sup>-1</sup> as dependent variables to check factors that correlated with them. Controlling for those factors, we examined the association between yield and the application of (i) fertilizer or compost based on the use of soil or leaf testing; (ii) tree density, and (iii) shade level.

## RESULTS AND DISCUSSION

For the seven provinces in Sumatra, 35% of the farmers grew Arabica which accounted for 18% of total coffee production. Most farmers in Northern Sumatra grew Arabica coffee (96%), while those who were in Southern Sumatra mostly grew Robusta (98%).

The survey found that an average smallholder coffee farmer had a coffee farm size of 1.15 ha, grew 2,427 trees, producing 645 kg of GBE (Green Bean Equivalent) coffee with a yield of 562 kg of GB ha<sup>-1</sup>, and generating gross revenue of IDR 19.5 million per year. The provinces with the highest farm size were Bengkulu (1.61 ha) and South Sumatra (1.58 ha) and the lowest farm size were North Sumatra (0.41 ha) and West Sumatra (0.57 ha). The yields were quite comparable across provinces in Sumatra, which was around 500 kg of GBE ha<sup>-1</sup>. Jambi and South Sumatra have relatively higher yields of 829 kg ha<sup>-1</sup> and 631 kg ha<sup>-1</sup>, respectively.

Comparing Arabica and Robusta farmers, on average Arabica farmers had smaller coffee farm size (0.68 vs 1.42 ha) and lower tree density (1,820 vs 2,143 trees ha<sup>-1</sup>). In addition, despite having smaller total production (340 vs 812 kg of GBE) and lower yield (536 vs 577 kg ha<sup>-1</sup>), Arabica farmers had an overall higher gross revenue (IDR 22 million year<sup>-1</sup> vs IDR 18 million year<sup>-1</sup>) than Robusta farmers due to higher price of Arabica coffee. The highest gross revenue from coffee farming was observed in Aceh (IDR 41 million year<sup>-1</sup>) and the lowest was in West Sumatra (IDR 7.4 million year<sup>-1</sup>). According to the Indonesian Ministry of Agriculture (2017), smallholders' production costs on average constitute 68.9% of the farm gate price. The reported earnings and expenses might put farmers in a vulnerable position to economic shocks such as in the event of drought, pest or disease infestation, or coffee price or production shocks. It is likely that this revenue was too low to cover the living expenses if the farmer's livelihood relies solely on coffee farming. It is in

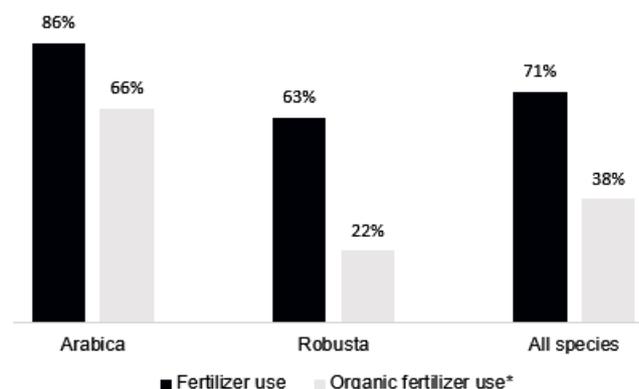
this scenario that improving yield takes utmost precedence. Despite this, when asked if their children would continue farming, majority of farmers (55%) said yes, which indicated their outlook towards future generations willingness to take up coffee farming as a profession.

In terms of the farming practices, there were more fertilizers used (86% vs 63%) but lower chemical used (68% vs 91%) among Arabica farmers compared to Robusta farmers (Figure 2). In terms of processing, Arabica farmers mostly sold their coffee as wet parchment (71%) and cherry (23%), while almost all Robusta farmers sold their coffee as green beans (97%).

When asked about the oldest coffee tree on the farm, many farmers (44%) reported having the oldest tree be between 11 to 20 years. In 2012, the Ministry of Agriculture estimated that 60% of Indonesia's coffee trees are more than 25 years old. The ministry allocated nearly IDR 143 billion (13 million USD) for Arabica expansion and Robusta rejuvenation (Neilson et al. 2015). The data collected through ECS should help the government to sharpshoot such investments where it is most needed.

### Fertilizer use and soil conservation

Fertilizer is an important contributor to coffee yield. We found 14% of the Arabica farmers and 37% of the Robusta farmers did not apply fertilizer on their farm (Figure 2). The number of farms that used compost or organic fertilizer varies significantly between Arabica (66%) and Robusta (22%) (Figure 2). Other studies (Wahyudi and Jati, 2012; Saragih 2013) also reported that coffee yield in Indonesia was still relatively low, covering at 50-65% of potential production, possibly due to limited fertilizer application. Commonly cited causes for low yield also relate to the old age of the coffee trees.



**Figure 2.** Percentage of farmers who use fertilizer and organic fertilizer by coffee species. Note: \*For the use of organic fertilizer, percentage for Arabica is from Aceh and North Sumatra, percentage for Robusta is from the rest of Sumatra. The questions that identified the use of organic fertilizer was updated for surveys in Aceh and North Sumatra

This limited use of fertilizers could be a limitation in improving yields. The analysis showed that the use of fertilizer (including both organic and inorganic) was associated with an increase in yield of 98 kg of GBE ha<sup>-1</sup> for Arabica and 124 kg of GBE ha<sup>-1</sup> for Robusta (Table 2). These estimates were significant at  $\alpha = 1\%$  level. The use of fertilizer is also associated with higher yield per tree (0.058 kg/tree for both Arabica and Robusta). In terms of revenue per hectare, on average, both Arabica and Robusta farmers that applied fertilizer had higher gross revenue per hectare of IDR 6.9 million/year and IDR 2.8 million year<sup>-1</sup>, respectively.

Neilson et al. (2015) highlighted the limited use of fertilizers (inorganic and organic) and inadequate attention towards maintaining soil fertility and conserving soil resources in Indonesia. Ibnu (2017) also stated that the production costs are relatively low, because most farmers make limited use of fertilizers. However, this turns out to also limit yields in Indonesia. Thus, it is necessary to educate the farmers to increase organic or chemical fertilizer application. Research results from the Coffee research unit at the Western Highlands Agriculture and Forestry Science Institute (WASI) in Vietnam, showed that applying fertilizers based on soil tests could save up to 30% of fertilizer while increasing yield up to 10% given the context that some farmers in Vietnam tend to overuse fertilizers (VCCB 2016). This will have an impact on input cost reduction, soil conservation, greenhouse gas, and sustainable production. The situation seems to be in contrast for Indonesia but the implication here is the benefits of soil tests in guidance of efficient fertilizer application.

In terms of sustainability, soil conservation is very critical in agriculture production. We found 79% of farmers did not apply any methods of soil conservation methods, 11% applied to mulch (i.e., coffee husk or peanut residue), 10% applied cover crops probably only for immature stage farms. Usually, mulching is not common for mature coffee, and not suitable for fertilization activities-farmers tend to rake and bury the tree residues. The most popular soil erosion control method was using natural barriers (12%), followed by contour planting, and replanting sloped areas (8% and 7%, respectively). Different techniques for soil conservation such as terracing, stabilizing grasses, etc. accounted for a small proportion.

### Tree density

The average tree density we found in Sumatra varied for both Robusta and Arabica (Figure 3). For Robusta, we observed an average tree density of 2,143 trees ha<sup>-1</sup>, and for Arabica 1,820 trees ha<sup>-1</sup>. This tree density in Sumatra does not seem optimal for neither Arabica nor Robusta varieties.

Our research found that the two Arabica growing regions of Aceh and North Sumatra had a low tree density

of 1,611 and 1,958 trees ha<sup>-1</sup>, respectively. Significant yield improvements could be achieved by helping coffee farmers to reach optimal tree density. For Arabica, the optimal density varied from one variety to another. The open growth variety (i.e., Mundo Novo) is normally planted at low density (1,200-1,600 plants ha<sup>-1</sup>). However, it can also be successfully grown at higher planting densities (3,000-4,000 plants ha<sup>-1</sup>) (Eskes and Leroy 2004). Dwarf Arabica variety (i.e., Caturra) seems well adapted to the growing conditions that prevail in Colombia and Costa Rica, where it has served as a basis for high-density planting (5,000-10,000 plants ha<sup>-1</sup>) (Eskes and Leroy 2004). In several countries, the best productivity results have been obtained with densities of 10,000 to 12,500 coffee trees ha<sup>-1</sup> (Descroix and Wintgens 2004). Nevertheless, to secure sustainable, long-term production and to allow access to the plots for maintenance purposes, producers prefer to plant 4,000-7,000 trees ha<sup>-1</sup>. This corresponds to a spacing between 2 m x 1.2 m and 1.7 m x 0.8 m (Descroix and Wintgens 2004). The density for Arabica that we found in our surveys, was far too low to this recommended range by other researchers. In Indonesia, the most popular varieties are Ateng which is a common name for Catimor coffees, followed by Sigara Utang-an improved Ateng selection of Timor variety with Bourbon, then Gayo (1, 2, 3) which is also a derived varietal of Catimor. Catimor is a hybrid of *C. Arabica* and *C. canephora* (Timor hybrid) with *C. Arabica* var. *catarra*, and it is advised that Catimor with compact canopy should be planted at high density of at least 3,000-4,000 plants ha<sup>-1</sup>.

Simultaneously, unlike the less-than-optimal tree density for Arabica, we found that the tree density for Robusta was higher than the optimal range. We found in the five Robusta growing provinces the tree density ranging from 1,364 trees ha<sup>-1</sup> in West Sumatra to 2,455 trees ha<sup>-1</sup> for Bengkulu. This is high for Robusta as the suggested density for Robusta worldwide can range from 1,250 to 2,220 coffee trees ha<sup>-1</sup>. In full exposure to sunlight, the optimal density is approximately 2,000 plants ha<sup>-1</sup>. Under shade, the density will be lower and will vary according to the density of the shade. The denser the shade, the lower the density of the coffee trees (1,250-1,660 trees/ha) (Descroix and Wintgens 2004). The density for Robusta found in our surveys was higher than the recommended range.

Our analysis shows that yield was positively correlated with tree density for Arabica coffee the correlation is 0.31 and for Robusta it is 0.67 (Figure 3). The regression analysis shows that 100 additional trees ha<sup>-1</sup> were associated with higher yield by 9 kg ha<sup>-1</sup> for Arabica and 15 kg ha<sup>-1</sup> for Robusta (Table 2). Despite that, the yield per tree basis decreased as there were more trees ha<sup>-1</sup>, showing the importance of planting an optimum number of tree densities for each species based on the research mentioned earlier.

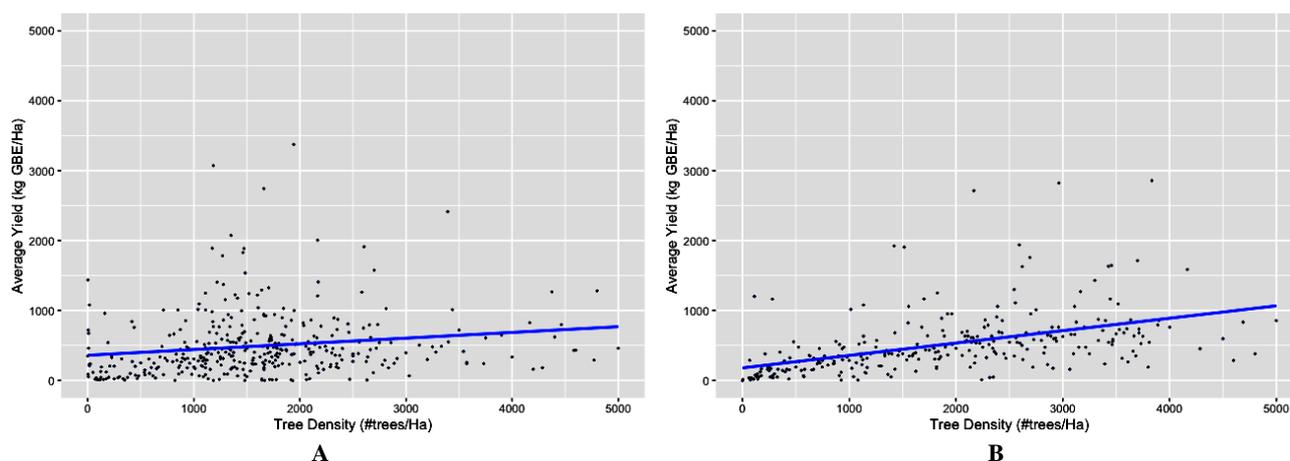


Figure 3. Scatterplot of yield and tree density for: A. Arabica, B. Robusta

Table 2. Regression analysis for several farming

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Arabica	Robusta	Arabica	Robusta	Arabica	Robusta	Arabica	Robusta
VARIABLES	Yield	Yield	Revenue (IDR 000)	Revenue (IDR 000)	Yield per tree	Yield per tree	Revenue/Ha (IDR 000)	Revenue/Ha (IDR 000)
<b>Farming practices</b>								
Type of shade = No shade (base category)								
Type of shade = Light/medium shade	-58.67*** [22.62]	-66.95 [81.07]	-1,731 [1,477]	10.24 [3,336]	-0.0349** [0.0142]	-0.012 [0.0458]	-3,785** [1,581]	-1,763 [1,952]
Type of shade = Heavy shade	-94.84** [41.54]	-114.9 [82.84]	1,737 [2,715]	-1,464 [3,409]	-0.0382 [0.0261]	-0.0368 [0.0468]	-6,807** [2,905]	-3,018 [1,995]
Tree density (trees/Ha)	0.0893*** [0.0113]	0.149*** [0.00766]	2.763*** [0.736]	3.629*** [0.317]	-8.49e-05*** [7.08e-06]	-7.73e-05*** [4.33e-06]	5.669*** [0.787]	3.271*** [0.185]
Use fertilizer	97.75*** [28.11]	124.0*** [14.53]	6,455*** [1,836]	2,670*** [600.4]	0.0580*** [0.0177]	0.0584*** [0.00822]	6,976*** [1,964]	2,832*** [351.4]
Do soil or leaf testing	-146 [89.50]	130.4*** [43.48]	-10,058* [5,812]	8,525*** [1,806]	-0.102* [0.0562]	0.0446* [0.0246]	-8,927 [6,220]	3,762*** [1,057]
Use chemicals	-7.907 [19.12]	-7.763 [24.77]	-1,386 [1,249]	647.7 [1,032]	-0.00333 [0.0120]	0.000398 [0.0140]	-1,569 [1,336]	121.9 [603.8]
Do pruning	32.12 [21.05]	36.71 [23.23]	505.3 [1,372]	-133.7 [965.1]	0.00892 [0.0132]	0.00413 [0.0131]	3,996*** [1,468]	1,119** [564.8]
Do replanting	20.44 [20.94]	22.09 [19.17]	925.2 [1,368]	-411.6 [790.6]	0.0111 [0.0132]	0.011 [0.0108]	1,714 [1,463]	714.9 [462.6]

**Shade level**

For this study, we defined light shade as 0-30%, medium shade as 30-60% and heavy shade as 60-100%. A predominant number (80%) of farms in Sumatra fell under light and medium shade, while 9% of the farms have almost no shade and 11% full shade. Leucaena, Albizia, and Gliricidia were the most popular shade trees in Sumatra accounting for 30%, 29% and 18% of farms, respectively.

We found the shade levels were not just appropriate but reverse. Arabica needs more shade, but 25% of farms surveyed had no shade, 69% of the farms have light and medium shade, and 6% of the farms had full shade. Robusta usually requires less shade than Arabica. However, among the Robusta farms, light and medium shade were observed in 86% of the farms, full canopy in

13% of the farms, and 1% of the farms had no shade (Figure 4.A). Other researchers such as Neilson et al. (2015) have found most coffee across Indonesia is grown under a relatively dense canopy of shade or as multi-strata coffee. The observed canopy levels in Indonesia where full canopy accounts for 11% was too high resulting in low production, and the medium shade of 46% was also high compared to the widely recommended level of shade.

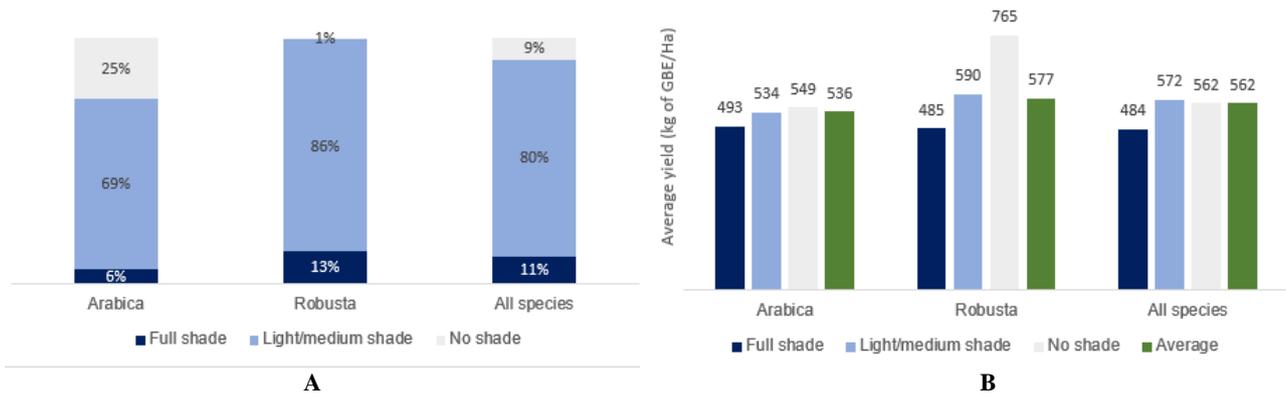
We found the level of shade had a negative correlation with yield i.e., higher yield observed in less shade farms, especially in Robusta (yield of 765 kg/ha for no shade tree vs 485 kg/ha for having full shade tree) (Figure 4B). Saragih (2013) also found that shade trees have significant influence on coffee production in North Sumatra (at  $\alpha = 10\%$ ). However, we also understand that shade management has its pros and cons. If the shade tree

population increases, coffee production decreases due to reduced flowering and competition between species for nutrients. On the other end, shade trees have a positive role in improving the coffee quality and bean size (Muschler 2004), and biodiversity. Our analysis also showed the tree productivity is highest for lowest tree density and none for medium shading. It decreases with higher tree density and is significantly lower when heavy shading is observed (Figure 5).

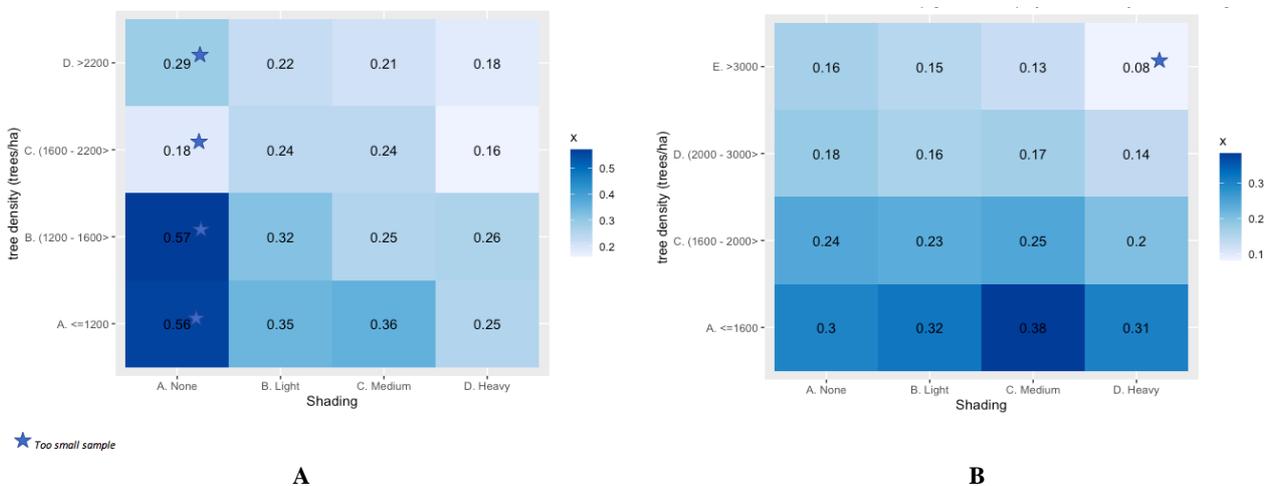
The best shade level varies with environmental conditions and production objectives. For low-altitude coffee zones (typically below 800 m. a.s.l.) with a pronounced dry season of 4-6 months, the suggested shade level was of 35-65%. Another study showed the rates of photosynthesis or growth of *C. Arabica* are highest at intermediate levels of shade, typically ranging from 30 to 50 % (reviewed by Muschler 2004). For Robusta, the shade should not exceed 40% as it will affect coffee production (Lambot and Bouharmont 2004). This level of shade would

favor leaf retention in the dry season and reduce the incidence of some diseases and weeds. Higher shade levels should be avoided because of the potential increase of the Leaf Spot, which is encouraged by higher humidity, a condition accentuated by shade. Conversely, lower shade levels should be avoided because of the increased incidence of Brown Eye Spot disease and of the Coffee Leaf Miner under unshaded conditions (Muschler 2004). Leguminous shade trees are the most commonly used in coffee plantations (Lambot and Bouharmont 2004).

Shade management requires significant research, as the role played by other trees in a farm plays a crucial role in promoting biodiversity and environmental sustainability. We recommend no one-size-fits-all approach here and recommend interventions that are tailored factoring in the farm level context, without compromising any of the three pillars of sustainability: environmental, economic, and social.



**Figure 4.** Shade tree level and yield. A. Distribution of shade tree level by coffee species. B. Average yield by shade tree level and coffee species (right)



**Figure 5.** Tree yield by tree density and shade level for: A. Robusta and B. Arabica

### Conclusion and policy recommendations

The Enveritas Coffee Survey is rigorous and possibly one of the largest studies conducted in Indonesia with an aim to promote coffee sector sustainability. Both the crop and the sector are of utmost importance to policymakers for the following key reasons: (i) coffee is one of the key export commodities; (ii) a significant portion of coffee producers are smallholder farmers vulnerable to economic shocks. Increasing the economic opportunities for coffee smallholders would lead to resilient rural communities, more export opportunities, poverty eradication, and importantly, to promote the inclusive and sustainable growth of the nation.

We started our analysis by exploring the variables that can have the maximum impact on the coffee producers. A comparative analysis of yield with other coffee-growing regions has given a clear indication that yield improvement is a priority. From the Enveritas Coffee Survey, we explored troves of data to understand the key variables that are associated with yields. We found three variables: (i) Fertilizer use was low among farmers, especially Robusta. There is scope to measure and improve soil health either through organic/inorganic fertilizer use and other soil conservation methods that can help increase yields; (ii) Coffee tree density: we found that there is a huge mismatch between the prevailing tree density in both Arabica and Robusta farms. By reviewing other literature, we have also presented the recommended tree density; (iii) Shade level: we also found that the shade levels among the coffee farms are not conducive to obtain optimal yield. We classified the farms into three shade categories and, after evaluating external research done on this topic, recommended best levels of shade. We also emphasized that shade management requires a farm-specific, tailored approach to increase yield potential without compromising biodiversity protection.

There are, however, limitations to our study. Our data collection and study focused more on the sustainability aspects of coffee farming, focusing largely on the social, economic, and environmental aspects. In-depth analysis of cultivation practices, soil, or climate are not part of the scope of this study. The factors, especially of nature, that influences a farm are hard to comprehend and will require years of research. Each farm is unique, and so is each farmer. By reaching out to thousands of farmers in some of the remotest places, we tried to present findings that could have a most positive impact. Using our research as a starting point, we would like to make the following recommendations as an area of future research or programs: (i) Conduct a rigorous study on each harvest to understand the yield figures across Indonesia's coffee-growing regions. Systematically understanding the progress on yields, preferably at a district level, will initially help understand the overall smallholder productivity landscape and later to implement and measure necessary interventions. (ii) Identify the prevailing prices of soil and leaf testing services and explore designing interventions to make such services affordable to farmers. (iii) Initiate a research program to understand the pathways to reach optimal tree density among both Arabica and Robusta

growing smallholder's farms. (iv) Initiate a research study to understand the aspects of shade management that are suitable for the Indonesian context. Such research should focus not just on yields, but also the role of shade trees in biodiversity and the ecosystem services that comes with it.

Our findings have valuable insights for policymakers, development organizations, and anyone interested in coffee sectors sustainability. This is especially prudent in a time the national government has been planning initiatives to make 2019 as the year of the Indonesian farmers' revival. Our findings also have implications for coffee value chain actors that are committed to sustainable supply chains. We acknowledge that understanding the key factors that influence yields is just one step towards developing robust policy recommendations for creating inclusive employment opportunities. Effective dissemination of agricultural practices through programs such as farmer field schools or demo plots is also of utmost importance.

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